PROFILES OF PROBLEMATIC SOILS AND SPATIAL DISTRIBUTION: IMPLICATION ON FOUNDATION CONSTRUCTION IN PARTS OF KOSOFE LAGOS, SOUTHWESTERN NIGERIA

Oloruntola M. O1., Bayewu, O. O2., Kehinde, K1., Obasaju, D. O1 and Mosuro, G. O2.
Department of Geosciences, University of Lagos. Lagos, Nigeria.
Department of Earth Sciences, Olabisi Onabanjo University, Ago Iwoye, Ogun State.
All correspondence to oloruntolamoroof@yahoo.com

ABSTRACT

Geotechnical data were complemented with geophysical investigation and employed to delineate problematic soils in parts of Kosofe Lagos, Southwestern Nigeria. The study area was chosen because of known issues regarding cracks in buildings and differential settlement of infrastructures founded on soils in the area. The aim is to generate profiles and maps of the spatial distribution of the subsurface soils to aid in foundation planning. Forty eight borehole logs and nine Vertical Electrical Soundings were compiled to delineate the different subsurface lithology which include peat, clay and sand. The results showed that the peat layer has maximum thickness of about 18.25 m but absent in some boreholes. This is underlain by clay unit with thickness ranging between 2.50-28.50 m. Sand unit constitute the third layer delineated with maximum thickness of 14 m. There is a general thickening of peat soils in the northern parts, especially around the streams in the area, which is instructive on the role of stream in the formation of the peat. The clay on the other hand is thickest around the northeastern and southeastern parts. The soil profiles generated reveal that the area is underlain by thick peat and clay having significant lateral, vertical variation and rapidly changing lithological facie over short distances. The extensive occurrence of these poor engineering soils calls for adequate engineering precaution in designs of building foundation.

Keywords: VES, geotechnical borehole profiles, problem soils, foundation, southwestern Nigeria

INTRODUCTION

Characterization of subsurface soils and determination of soil strength are prerequisite for the foundation design of important civil engineering structures (Sudha et al., 2009). Studies have identified peat/soft clay as problematic soil associated with foundation failures. It is however very important to delineate and characterize foundation soils especially in coastal areas with highly compressible soils. Several methods have been proposed in various studies (Akinlabi and Adeyemi, 2014, Hatta et al., 2015, Kirar et al., 2016, Szokoli et al., 2017) for the assessment of foundation failure based on various concepts from geotechnical tests (Standard Penetration Test (SPT) and Dutch Cone Penetrometer Test (DCPT)) in association with the borehole data and laboratory measurement of soil properties (e.g. grain size distribution, degree of saturation and permeability) to characterize the subsurface soil. The indirect non-destructive geophysical methods, such as electrical resistivity and seismic refraction, are increasingly being used in combination with the borehole, pressure probe and other geotechnical investigations such as Standard Penetration Test (SPT) in foundation studies. The application of electrical resistivity for characterization of soil was employed as complementary techniques by Samouëlian et al., (2005). Kamal et al., (2015), Oyedele and Olorede (2010) in geotechnical studies, commonly using Standard Penetration Test (SPT). Previous researches of soil profile mapping have also used integrative, in particular they have combine methods such as Vertical Electrical Sounding (VES) and or resistivity traversing, geological investigative and Laboratory test/analysis, Geographic Information System (GIS) visualization to delineate the soil profile (Sevnur and Mehmet, 2015; Ayolabi et al., 2012, Saeid Hashemi et al., 2010, Oyedele et al., 2012, Adeoti et al., 2009). These studies are mostly localised, based on few data and largely cover areas of less than 3000 square meters. The spatial distribution and variation of the different lithological facies within the subsurface remained unresolved in many areas. Hence, maps of the spatial distribution of these problematic soils and their thicknesses which could help in reducing incidences of structural failure (Fig. 1) and planning foundation investigation in these areas are totally unavailable. In this study, geophysical and geotechnical methods were employed to map the spatial and vertical characteristic of problematic soils at Kosofe for geotechnical and civil planning purposes. This study aims at producing lithological maps that will assist in the execution of civil engineering programs in Kosofe and its environs in Lagos, South western, Nigeria. The importance of this study is underscored by the fact that the spatial distribution maps of the problem soils could serve as fundamental guide to design and construction of safe engineering/civil structures (Meshida and Ayolabi, 2011).

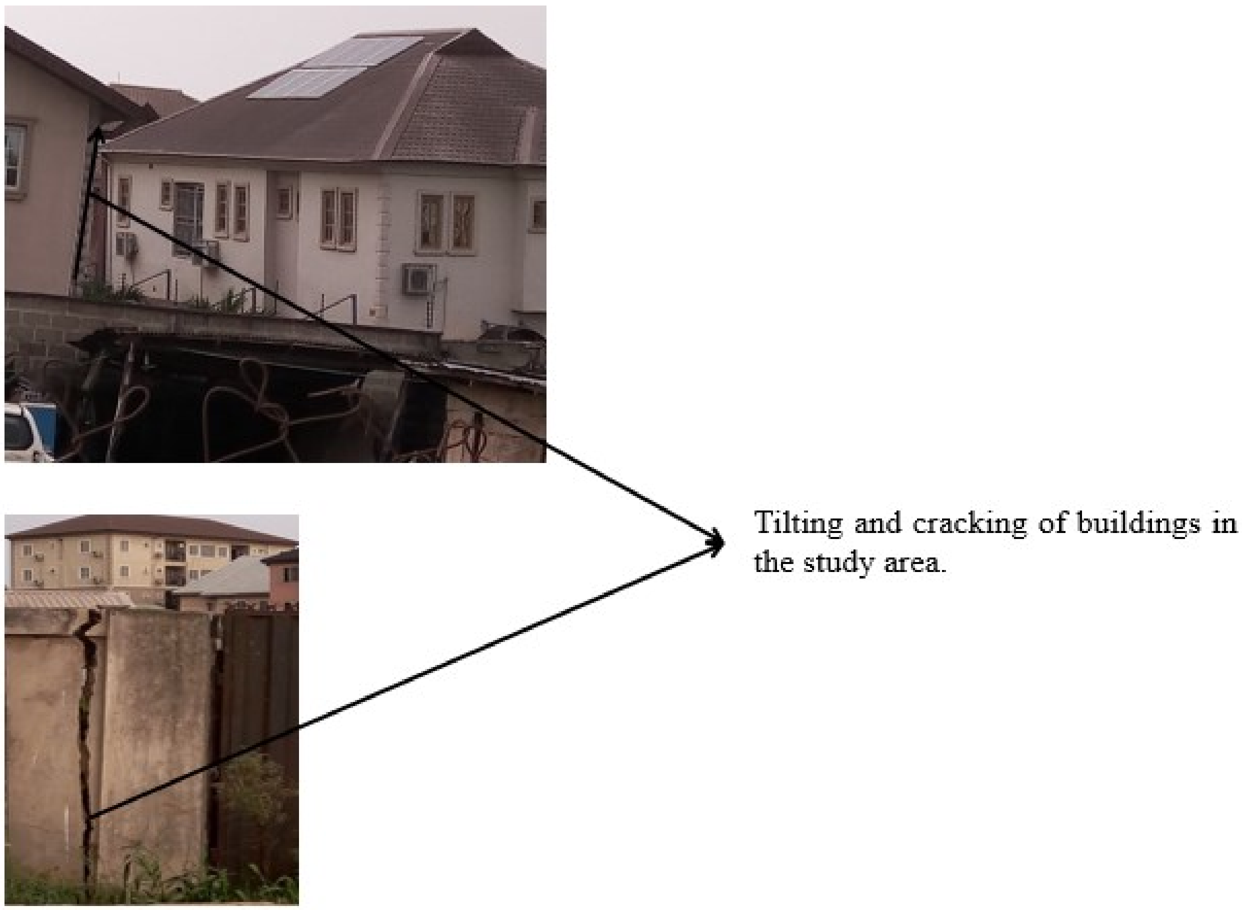

Fig. 1: Evidence of Structural Failure of Buildings in the Study Area

The Location and Geology of the Study area

This study focuses on an area of approximately 6.5 km^2 in Kosofe, located at the centre of Lagos State (Fig. 2) and lies within latitudes 6^0 32'30.2"N - 6^0 34'30.02"N and longitude 3^0 22' 0" E - 3^0 24' 0.94" E. It is accessible and connected by three major highways: The Third Mainland Bridge, Oshodi – Gbagada Expressway and Ikorodu road. The monthly mean temperature is usually high between November to March, while rainfall and Relative Humidity are high between June to September of each year except August. The annual mean temperature of 27.20 °C and Relative Humidity of 83.01% in the coastal region. There are however, some exceptionally hot days (34-35.3 °C) with high Relative Humidity between February-April (Salau, 2016). The study area is developed in terms of infrastructure and the population is high as in other parts of Lagos due to construction activities, housing and other social amenities. Geologically, the area lies within Dahomey Sedimentary Basin and belongs to the Coastal Plain Sands, which incorporates exposures of sedimentary rocks, ranging from silt, clay and fine to coarse grain sand. The exposed rock units in the area consist of poorly sorted sands with lenses of clays. The sands are in part cross-bedded and show transitional to continental characteristics (Omatsola and Adegoke 1981)

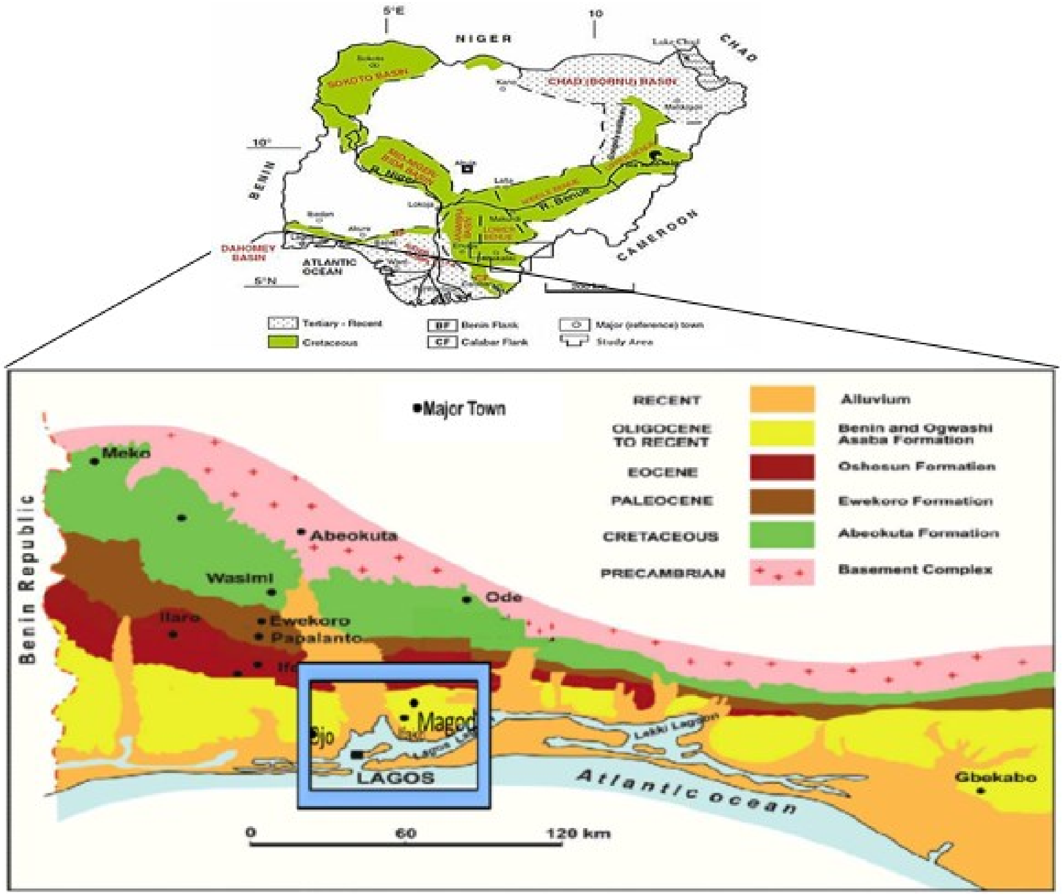

Fig. 2: Map of sedimentary basin of Nigeria showing the study area (Obaje 2009); Inset: Geological Map of Dahomey basin showing the study area (modified from Omatsola and Adegoke 1981)

Methodology

The profile and spatial distribution of the problem soils were studied using forty eight (48) geotechnical borehole logs (obtained from geotechnical companies) with depths between 16 – 30 m across the entire area and nine (9) Vertical Electrical Sounding (Fig. 3) that were divided into five profiles. At a location (borehole log 36, VES 08), the two tools coexisted and their results were correlated so as to see the reliability and authenticity of a single tool in locations where the other is not available (Fig. 4). For the VES, ABEM SAS 1000C Terrameter was used and a Schlumberger electrode configuration with a maximum current electrode separation of 100 m was employed. By injecting low frequency electrical current (I) into the ground with two current electrodes, the resultant voltage (V) between two potential electrodes was measured. The current was made to penetrate deeper into the subsurface by step-wise increasing the distance between the outer electrodes. The values of apparent resistivity were obtained by multiplying the resistance (V/I) displayed by the Terrameter with appropriate geometric factor (K). The apparent resistivity represents the average resistivity of the ground to a median depth of current penetration (Wilson et al., 2006). The VES data were processed by partial curve matching technique and further computer iteration with the aid of Winresist software (version 1.0). The borehole data were taken directly from the geotechnical logs helped to constrain the VES data as well as interpretation of the processed VES results. From the processed curves, the resistivities, thicknesses and depths of the subsurface lithologies were obtained.

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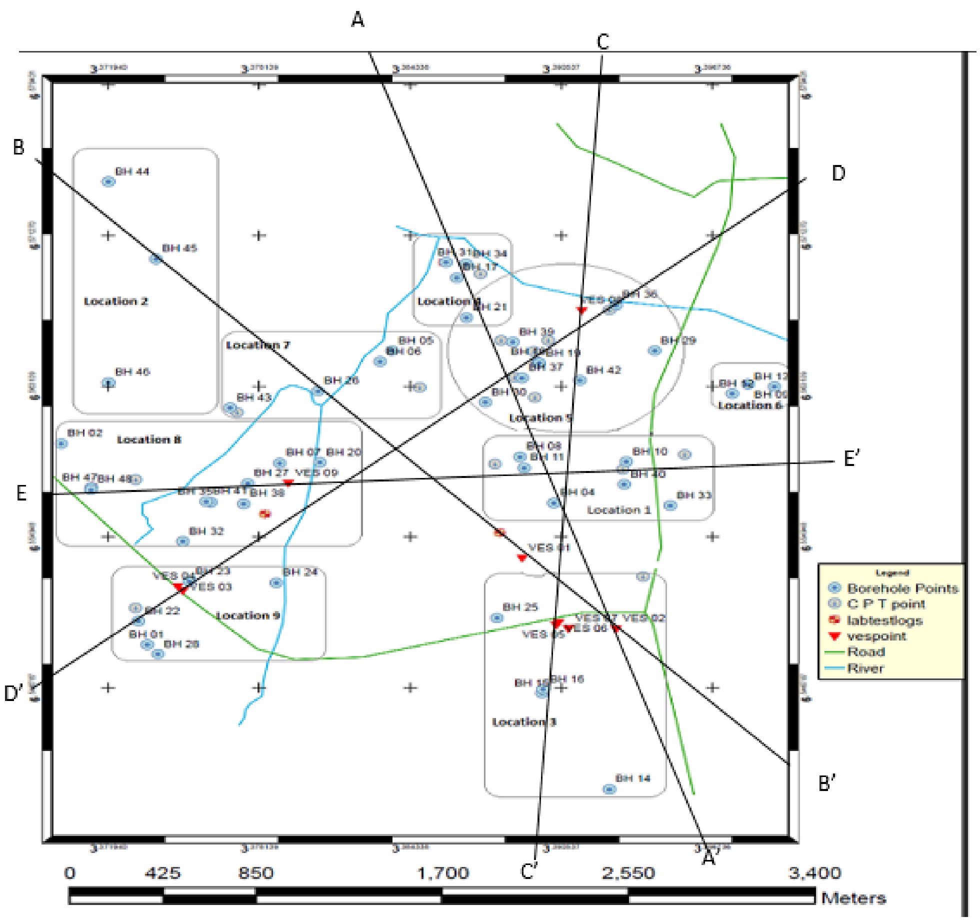

Fig 3: Spatial distribution for the acquired data showing the positions of the borehole logs and the VES points

Results and Discussion

Table 1 shows the summary of the results of the borehole logs and the VES data and Fig. 4 shows the correlation of the coexisting borehole log 36 with VES 8.

The borehole logs obtained were used to constrain the interpretation of the VES data. Based on this, a range of resistivity values was assigned to various lithologies in the study area. Resistivity range of <20 Ωm, 20 – 65 Ωm and > 65 Ωm corresponds to peat, clay and sand lithology respectively (Table 2).

Table 1: Summary of Geotechnical Borehole log and VES Data

BH No.	Peat thickness (m)	Clay thickness (m)	Sand thickness (m)
BH 01	12.75	9.75	7.00
BH 02	9.00	10.25	7.25
BH 03	13.00	9.75	6.75
BH 04	-	18.00	-
BH 05	16.50	10.50	5.50
BH 06	12.00	8.75	5.50
BH 07	3.00	3.00	14.00
BH 08	3.00	28.50	4.50
BH 09	0.75	8.25	6.00
BH 10	0.50	7.50	8.00
BH 11	0.75	12.00	8.25
BH 12	7.50	2.50	6.00
BH 13	0.75	8.25	6.00

BH 14	0.75	7.50	13.75
BH 15	-	23.75	5.25
BH 16	-	10.50	5.50
BH 17	-	5.25	5.25
BH 18	3.00	19.75	5.25
BH 19	4.50	16.50	5.25
BH 20	-	20.70	5.00
BH 21	10.50	13.50	6.00
BH 22	7.50	4.50	8.00
BH 23	-	26.00	4.00
BH 24	-	7.50	12.50
BH 25	4.50	21.50	2.50
BH 26	6.45	11.50	10.50
BH 27	3.30	14.00	12.00
BH 28	6.75	7.50	6.75
BH 29	12.00	7.50	9.00
BH 30	9.00	7.25	11.25
BH 31	5.50	5.50	5.50
BH 32	-	12.50	6.50
BH 33	4.00	14.25	7.50
BH 34	6.00	3.75	15.25
BH 35	7.25	12.00	6.75
BH 36	11.25	3.75	10.50
BH 37	9.75	7.50	5.50
BH 38	10.50	9.00	10.50
BH 39	18.25	6.25	4.50
BH 40	1.25	18.75	9.00
BH 41	8.25	7.50	9.00
BH 42	3.00	26.25	2.75
BH 43	12.45	7.50	10.05
BH 44	-	22.95	7.05
BH 45	-	20.00	10.00
BH 46	7.50	9.75	4.50
BH 47	5.25	6.75	17.25
BH 48	-	18.50	11.25
VES 01	-	19.50	19.50-??
VES 02	-	13.10	13.10-??
VES 03	-	28.10	28.10-??
VES 04	-	15.80	15.80-??
VES 05	-	15.00	15.00-??
VES 06	-	15.00	15.00-??
VES 07	0.80	12.30	12.30-??
VES 08	12.70	2.60	15.30-??
VES 09	12.30	6.50	18.80-??

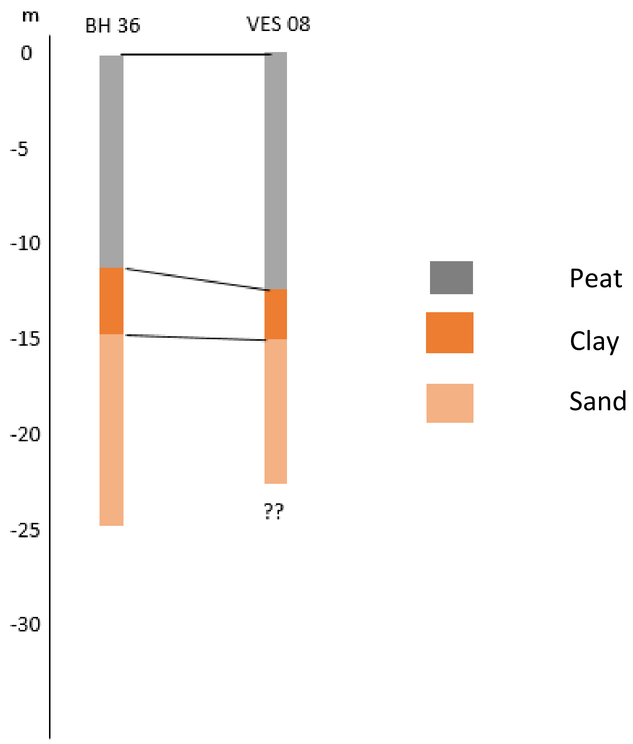

Fig. 4: Correlation of the coexisting borehole log 36 with VES 8.

Table 2: Range of Resistivity Values for Lithologic Characterization

Resistivity Range (Ohm-m)	Inferred Lithologies
< 20	Peat
20 – 65	Clay
> 65	Sand

The good correlation between the borehole log and VES shows that either of them could be independently used in any of the locations to delineate the subsurface lithology.

VES and Geotechnical Borehole Logs

In order to understand the spatial variability and distribution of the problem soils, five section lines as shown in Figs 5 – 9 were correlated to produce profiles of the subsurface lithology over various orientations. These sections provide the evidence for the distinct horizontal and vertical variations of the problem soils (peat and clay) of the study area.

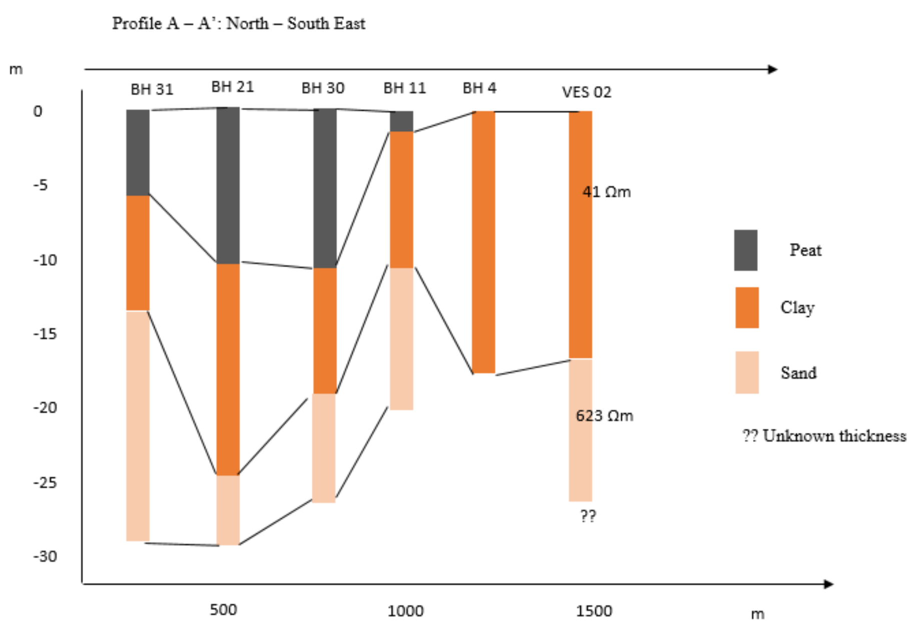

Fig. 5: Profiles of the subsurface lithology for profile AA^I^

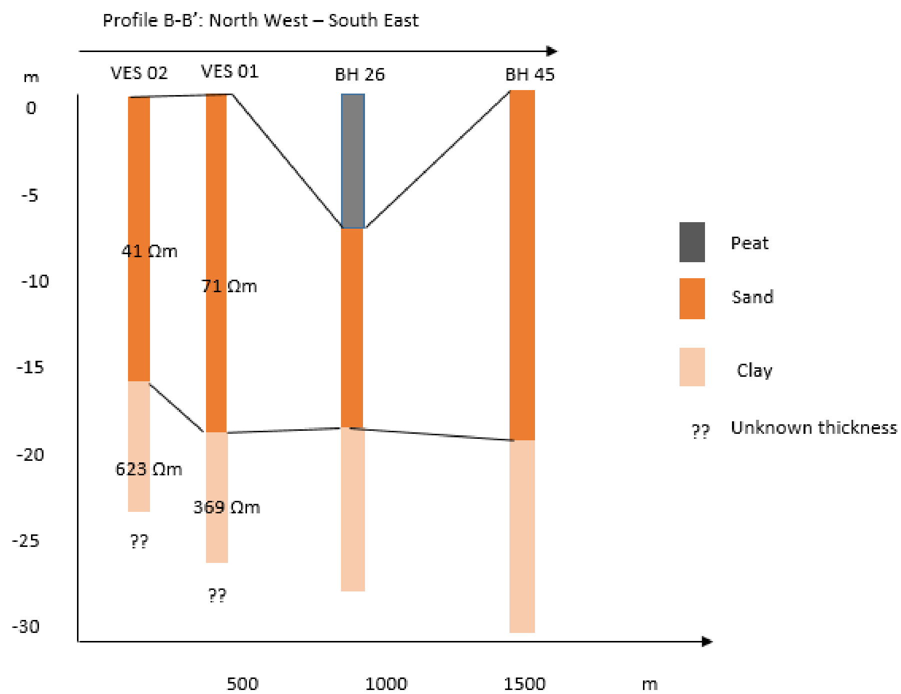

Fig. 6: Profiles of the subsurface lithology for profile BB^I^

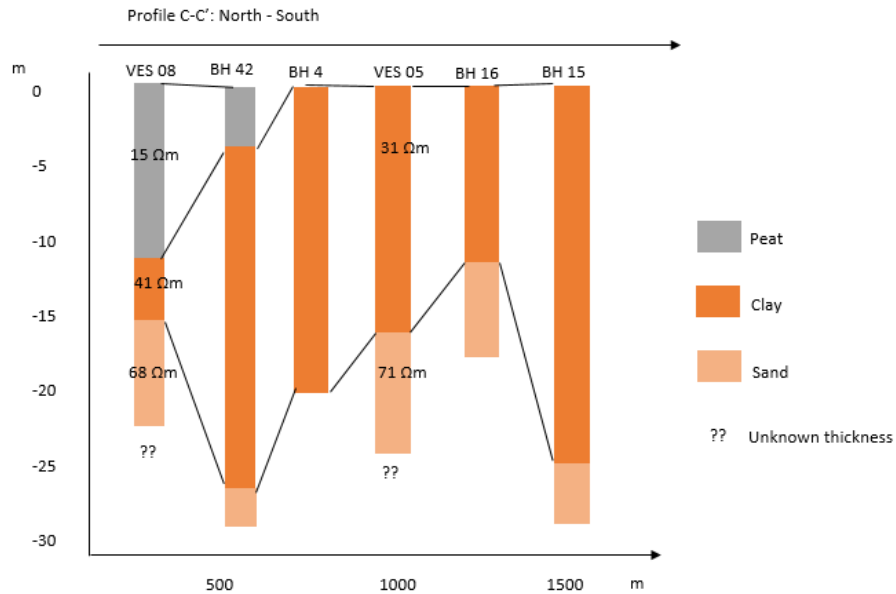

Fig. 7: Profiles of the subsurface lithology for profile CC[I]

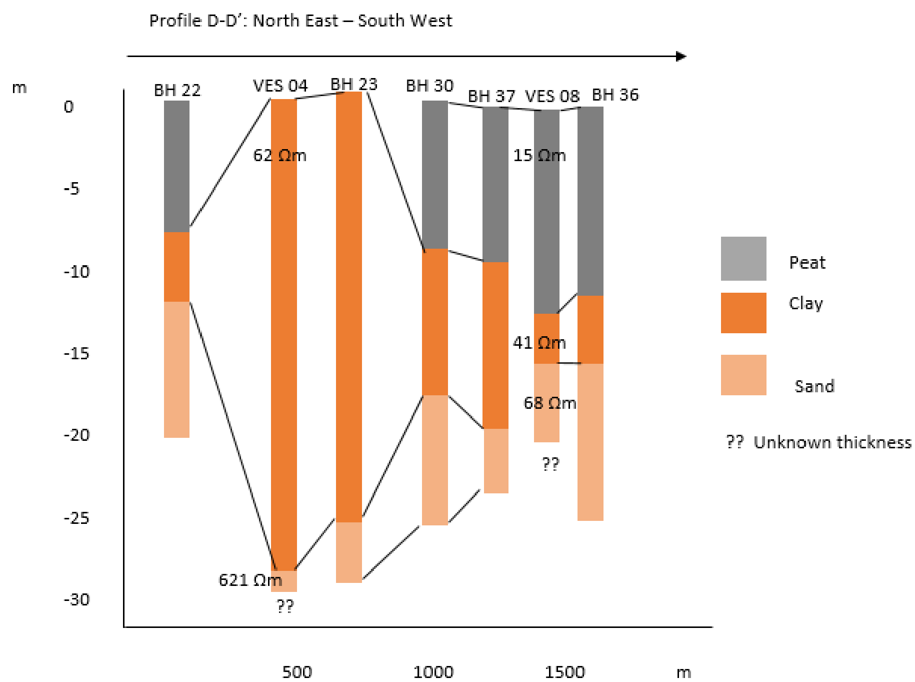

Fig. 8: Profiles of the subsurface lithology for profile DD[I]

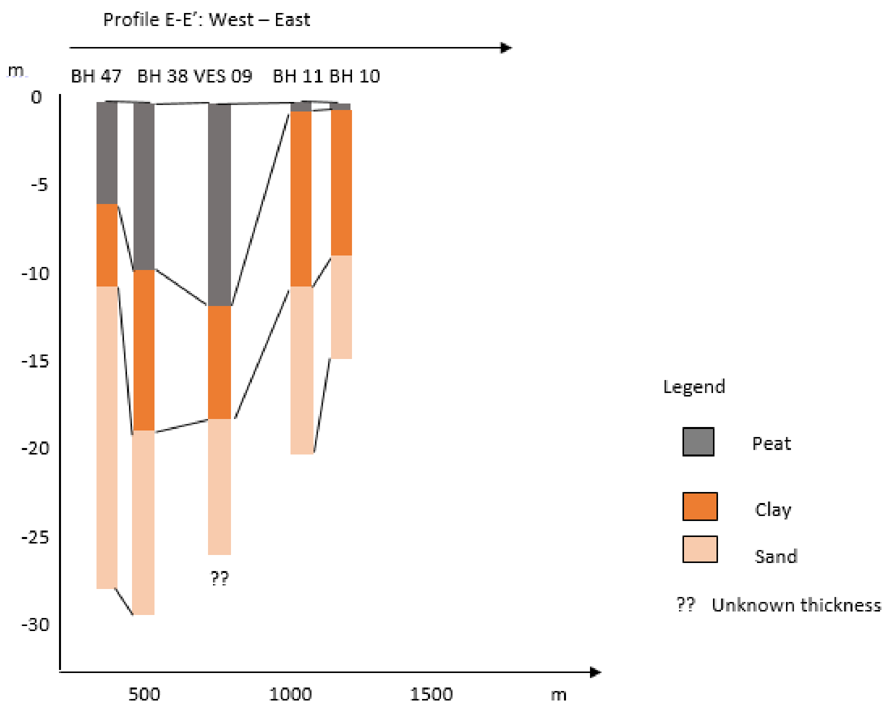

Fig. 9: Profiles of the subsurface lithology for profile EE^I

From the correlation of the borehole profiles and the VES, three distinct subsurface layers; peat, clay and sand can be identified. The peat is of variable thickness but generally less than 20 m. The next lithology corresponds to a clay layer, whose maximum thickness is approximately 29 m. The last layer is sand with maximum thickness of 14 m in the boreholes. It is observed that the occurrence and thickness of the peat is closely related to the streams traversing the area. The peats are found around the stream and are thicker in boreholes located close to the stream. Thus, the water body must have favored the formation of peat lithology. In some parts of the area, the peat facie is continuous, though thins out (Figs 5, 7 and 9) while along other profiles (B-B' and D-D'), there is rapid disappearance of the peat facie over a short distance (Figs. 6 and 8). Decomposed plant mixtures were accumulated and the stream aided the rapid deposition and burial of sediments over them, thus, creating anoxic environment for the deposited plants to become peat. Peat forms when plant material is unable to decay completely. This usually occurs in wet areas that do not provide the correct acidic and anaerobic conditions for full decay. Atmospheric temperature must be warm enough for plant growth but also low enough that microbial activity is disrupted so that plant matter does not break down completely. Organic materials are then accumulated under these conditions and peats are then formed (Kurbatov, 1968). Peats constitute grave problems in construction as a result of their characteristic long-term consolidation settlements even when subjected to a moderate load (Jarret, 1995).Thus peats cannot support foundation in their natural state (Duraisamy et al. 2007). When under structural loads, the compressibility characteristic could result into differential settlements, cracks in the wall and eventual collapse of the building. Fig. 10 below is the map of peat thickness in the study area which shows that the stream (water body) in the area which discharge directly into the lagoon plays a major role in the lithologic sequence and deposition of peat soil in the study area.

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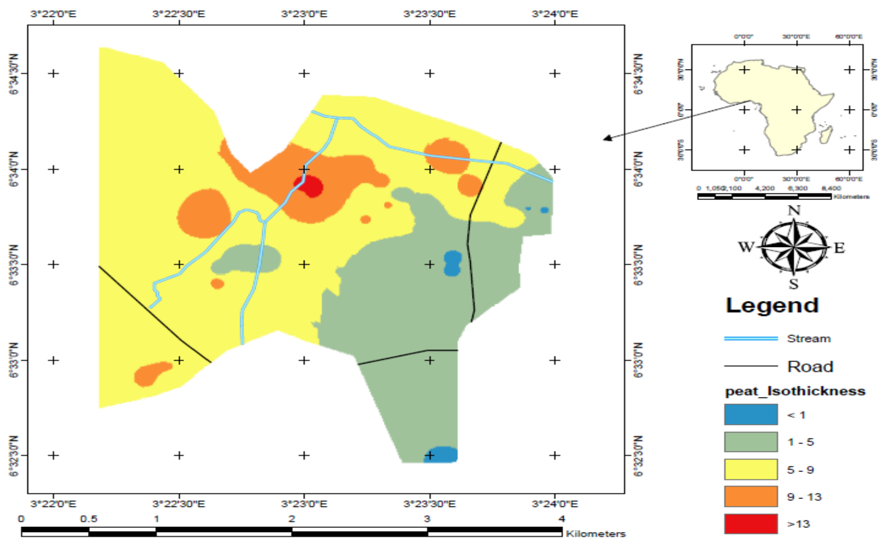

Fig. 10: Map of Peat Thickness in the Study Area

Clayey soils could also constitute problem to foundation founded on them because a change in the moisture content of clay soils can cause it to swell or shrink. Clay can exhibit large settlement under load and these settlements are likely to occur slowly due to its poor drainage characteristic. The settlement which could be haphazard in nature would ultimately lead to collapse of the civil structures constructed on it. Fig. 11 shows the geotechnical thickness map of the distribution of clay in the study area.

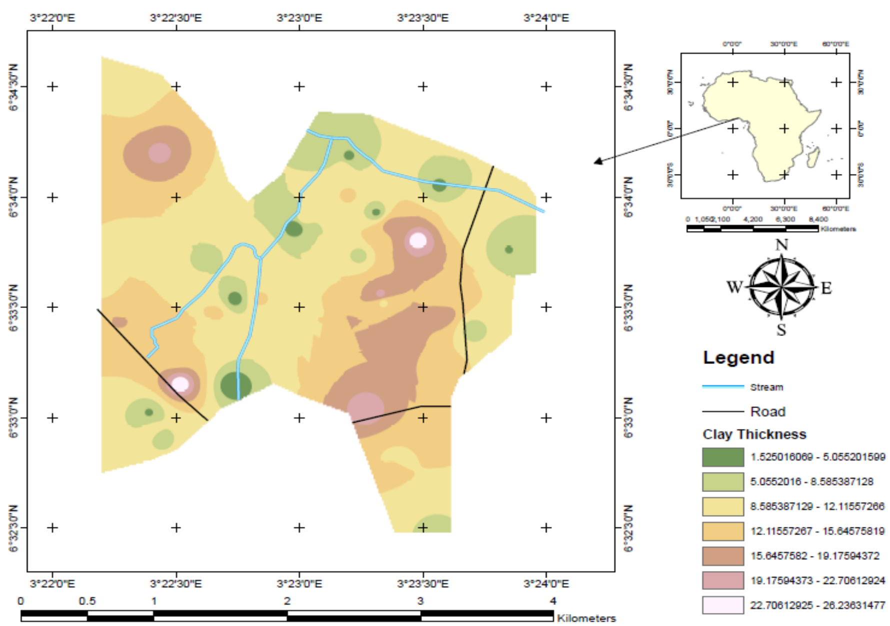

Fig. 11: Thickness map of the distribution of clay in the study area

While the peaty soils are thickest around the northern part of the area particularly around the stream, the clayey soils have high thickness across the whole area, but particularly in the northeastern and southeastern parts of the area. The variations in occurrences and thicknesses of the peat and soft clay layer along the profiles in some parts of the area are occasionally sporadic , disappearing/reappearing and thinning out over short distances (distances of less than 100 m). This could have great implications for structural stability in part of the area where foundation studies are limited to geotechnical investigations.

CONCLUSION

Coastal communities, such as Kosofe in Lagos, Nigeria is susceptible to foundation problems and has a long history of structural defects; most are not reported and are demolished when the differential settlement of the foundation soils result into tilting and cracks in the civil structure. This paper investigates the combined use of geotechnical and geophysical techniques to assess subsurface soil of coastal origin. The study area was chosen because of known issues regarding cracking and differential settlement of infrastructures founded on it. The profiles and spatial distribution of the problem soils (peat and clay) were studied using borehole logs and VES along five traverses. The extensive occurrence of poor engineering soils and the observed rapidly changing lithological facie call for adequate engineering precaution in designs of building foundation in the area.

The results of the geotechnical borehole logs and the VES showed that the study area is underlain by varying thickness of 'problematic soils' occurring throughout the area, sometimes sporadic occurrences of the peaty soils. It is thus recommended that shallow foundations should be avoided where the problematic soils are very thick and that some forms of soil improvements be applied where shallow foundation might be considered possible.

The maps and profiles of spatial distributions of the problematic soils in the area generated would serve as a tool to harmonize geotechnical foundation construction with the geological environment.

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